EFFECTS OF RELIEF CONFIGURATION AND HUMAN INTERVENTION ON THE NATURE OF THE KARST PROCESS

DR. LÁSZLÓ JAKUCS

My observations have completely convinced me that the distributions of the components of karst erosioninclu de certain features that are unexplained either by differences in lithology, by concrete differences in climatic factors representing the situation of the karst region in a climatic zone, by structural pre- or postformation, or by the relationship of the karst to its not karsted surroundings.

When it is recalled, for instance, that most of the dolines on a karst surface have a ground plan that is not circular but elongated in some direction, as a result of which one of the doline flanks is almost invariably much steeper than the others, one is already in possession of a relationship with a bearing on the causal relations of this problem. Mapping of the asymmetries of a variety of dolines revealed that the factors determining the ground plan of the depression in the course of its evolution are not the relationships studied and published by early authors (J. CVIJIC A. GRUND, J. CHOLNOKY, etc.), notably the dip of the strata and thelines of structurally preferred orientation, but rather some other factors influencing the dynamism of corrosion that the authors mentioned were not aware of; these factors overcome the preferred orientation due to the dip and strike of the strata, to impress upon these forms an orientation depending on the points of the compass. In other words, *independently of* whether the strata dip north, south, east or west, *the doline flanks with by far the highest relief energy*, for instance in the Bükk Hills and on the North Borsod Karst, *are invariably the flanks of easterly or north-easterly exposure.*

However, from the recognition of this phenomenon it is still a far cry to the drawing of general conclusions, which requires the analysis of a number of further examples.

It is known that the karsts of our planet are in various stages of erosion and of geographic relief evolution. The present-day aspect of the landscape provides us with the resultant of all the forms from previous episodes of relief evolution. *The actual (temporal) cross-section of the succession of events, reflected in the set of relief forms, is not merely the complex upshot of all the preceding episodes of relief evolution, however, but is itself a dynamism-controlling factor affecting relief formation in the present and in the future through its qualitative and quantitative driving factors.*

This rather general statement, intentionally formulated rather broadly, expresses an important feature of the evolution of any relief, and not just of the karsted ones; however, in adducing proof for it we shall remain within the confines of karst science.

Given a leaching solution of fixed quantity, temperature and chemical composition, karst corrosion on the surface is the more efficient, the more extensive the rock surface in contact with unit volume of the solution during unit time. *The extent* *of the surface is relative, however, and a function of palaeographic events.* At the beginning of the process of erosion, a limestone plateau not yet provided with a karst relief offers to erosion precisely one square kilometre of surface per square kilometre of map area (disregarding, of course, the internal fissures and joints). However, owing to the intense dissection of the relief by advanced doline sculpture on a limestone plateau of advanced karstification, one square kilometre of map area may actually correspond to 1.5 square kilometres or more of actual rock surface. The rates of erosion of a young and an old karst relief differ purely for this reason, if for no other.

There are other reasons too, however. Karstification widens part of the fissure grid draining surface waters into the rock mass. The widened fissures with their reduced wall drag attract a substantial proportion of the water pulled down by gravity. Hence, whereas early in the process of karst evolution, when all the fissures were still narrow and *the three-dimensional karstification of the young karst mass was still homogeneous,* even the narrowest fissures could contribute to the drainage of the descending waters, the advancing maturity of karst evolution gradually resulted in *a linearization of vertical drainage,* thereby reducing the total area of the surface in contact with the leaching solution in the interior of the karst mass.

As a consequence of all these factors, *as erosion advances the efficiency of surface corrosion increases, while the efficiency of corrosion within the karst mass gradually becomes linear.*

This set of examples may be followed still further. The partial increase in slope angles resulting from the formation of dolines promotes not only a faster surface run-off of precipitation, but also soil erosion and hence the natural baring of the karst rock. This process may reduce the efficiency of karst corrosion in the areas of steep doline and valley *flanks,* whereas it may increase it on the doline and valley *floors* characterized by the confluence of waters and the deposition of sediments; in contrast, beyond a given limit (that of the critical impermeability of the deposits), it may eliminate the process altogether.

In order to present a wider proof of our theorem, some back-acting channels of a different nature should be pointed out.

In numerous karst regions, including Yugoslavia, Italy, Austria, Cuba, South China, etc., it is obvious that *the size of the karst mass* itself may result in qualitative differences in karst erosion. For instance, in the authigenic karst mountains of Slovenia, Croatia, Albania, etc., several hundreed square kilometres in extent, even the A-type lenticular zones exhibit a B-type motivation, purely *because of the volumes of water* involved in their sculpture.

To consider another example of a different type, snow accumulated in the hollows of well-developed, deep dolines on karst plateaux, fallen in the winter and swept together by the wind, may persist well beyond the general snow-melting characteristic of the region as a whole. Masses of snow in striking contrast to the blossoming countryside can be encountered quite frequently in May and June in hte peculiar microclimatic spaces of temperate-zone dolines. Beneath these snow-covered spots the karst process is, so to speak, put into a deep freeze; that is, it will be many times less efficient than in the snowless surroundings: even though the gradual melting of this long-lived snow ensures a continuous supply of infiltrating cold water, this cannot vie with the high corrosive potential of the soil solutions, due to the vegetative production of CO_2 in the rhizospheres of the verdant surfaces close by.

Many similar examples could be enumerated, as the number of back-acting channels by which a set of karst forms, once developed, may and does react upon the complex of morphogenetic processes controlling the further course of evolution is very large. These back-acting channels have all been included under the heading of *geomorphological variance in karstification,* as they express the highly manifold and significant influence, also highly variable in both space and time, of the *geomorphological features* of the present-day landscape, developed during the prior evolution history of the karst. In a concise formulation, probably unusual on a first hearing, but certainly expressing the essence of the matter, we might say that *geomorphological variance in karstification means the influence of the karst topography upon karstification.*

Karst forms and, of course, the relief forms typical of any other type of landscape as well, are *not* in this sense mere *passive* products of erosion, etc., but undeniably active, *indirect relief-forming, process-controlling factors.*

I am therefore of the opinion that a systematic, analytical study of the above effects, and of a number of other effects not touched upon here, may be one of the primary tasks of morphogenetics in the future, since a full and realistic genetic understanding of a landscape on today's exacting level of sophistication in our science makes indispensable an analysis of the manifold *interactions* initiated by earlier erosion in the qualitative and quantitative parameters of subsequent erosion.

I am convinced that a profound understanding of cause-to-effect relationships in morphogenetics will be impossible on an up-to-date level without studies of the sort outlined above.

Further, any natural region and the human society living there will indisputably interact on many levels, just as there are similar, variable interactions between endogenous and exogenous dynamics, and the actual state of the relief at any instant. The problems that arise are to decide what agencies are enhanced, and where, at any given instant in the interaction of region and society, and in what measure these enhanced agencies affect the tendencies of continuing evolution of the human community and of the landspace itself.

The influence upon the evolution of society of the orographic, hydrographic, climatologic, petrographic, etc. features of a geographic environment has been studied in the last few decades with a great deal of care, and discussed from many aspects by modern geographical science. As a result, it has been possible to reject most of the one-sided, distorted approcahes: geographic determinism as one extreme, and the total negation of the importance of all these effects as another, or the exaggeration of the role of society to the point of a geographic biologism.

Present-day geographical science tends to attribute importance to these problems in keeping with their real weight, and devotes a great deal of painstaking effort to the study of the effective relationships; by learning the laws of their spontaneous manifestation, it is hoped to find reasonably practicable ways of applying these laws to a positive control of nature, most appropriate to the requirements of the society. The final aim and the *raison d'etre* of the scientific research is concretized in these studies; of the numerous relevant volumes that have been published, many have contributed viewpoints of inestimable value to concrete, national economic planning.

Under the conditions of a karst region, its interactions with the human communities living in and off it are perhaps even stronger than in regions of a different nature. The almost total lack of available water on extensive karst plateaux, most often coupled with a practically complete absence of agricultural land are highly unfavourable to the settling and evolution of cultures, even the minimum requirements barely being supplied. This is the main reason why, in the largely karsted state of Crna Gora (Montenegro) in Yugoslavia, the population density is only 33 per sq. km, whereas in the adjacent state of Serbia it is 86 per sq. km, with corresponding significant differences in the ways of life, the living standards and the cultural demands of the two peoples.

In keeping with the morphogenetic aims of the present work, however, I do not intend to highlight this aspect of karst regions and the social communities embedded in them, but rather the modes of expression of anthropogenic effects in the qualitative and quantitative evolution of karstification, and which may be included under the heading of the *anthropovariance* of karst evolution.

It may be stated as a general preamble that these effects usually influence the karst process very intensely, even though their reflection in land forms may as yet be unmeasurable, *the duration of their action having been too short* on a geological time scale. They may fundamentally and recognizably alter the *tendencies* of surface evolution, however, by initiating a completely new "cultural denudation", giving rise to a landscape altogether different from a landscape subject to its own laws of spontaneous evolution.

All this will now be illustrated by the presentation of certain important anthropovariantal modifiers of erosion. The topic discussed will be *modifications in erosion due to changes in the natural plant cover of a karst region.*

It is common knowledge that the huge demands in industrial timber required for the building of Venice, and for the construction of the Adriatic fishing fleets and the men-of-war and trading vessels of more recent times were tantamount to a death sentence for the forests in near-shore areas of the Croatian and Dalmatian karst. Complete deforestation was naturally followed by large-scale soil erosion, and the karst-type ablation of the steep hillsides soon resulted in the total and irreversible denudation of the region.

In Albania and especially in Greece, on the other hand, it was the tremendous multiplication of goats some centuries ago that was responsible for deforestation and denudation; feeding on buds and young shoots, and thereby killing off replacement growths, goats caused the ageing, senility and decay of woods and forests, thus opening up the way for the total ablation of the soil deprived of its reinforcing network of roots.

Soil erosion was also promoted and accelerated by the mechanical effect of trampling by the herds. In a short while, the multiplication of stray goats and the undesirable consequences of this reached such a degree that the animals could not find sufficient food, while the little agricultural land that did remain could not provide even the minimum sustenance to a population living even at the best of times on the meagre agricultural produce. Thoughtless interference with nature therefore resulted not only in the upsetting of the biological equilibria, but also in a profound change in the character of the land, in a reduction of its agricultural productivity and naturally also in qualitatively new features of erosion.

Based on the comparative analysis of wide-ranging phytogeographical data, P. JAKUCS (1956) first demonstrated consistent connexions between the form types of limestone lapies and the plant associations thriving in the karst region. One consequence of these connexions is that, whereas the *primary lapies reliefs* (Fig. 1) of karst areas bearing a sufficient soil and plant cover are places of intense subcutaneous lapies formation, resulting as a rule in *rounded microforms and root holes of irregular pattern,* these forms have been altered by subsequent denudation and exposure on the surface, giving rise to the *typical furrow and rain-rill set of karst forms typical of high mountains,* as a result of these secondary processes (Fig. 2).

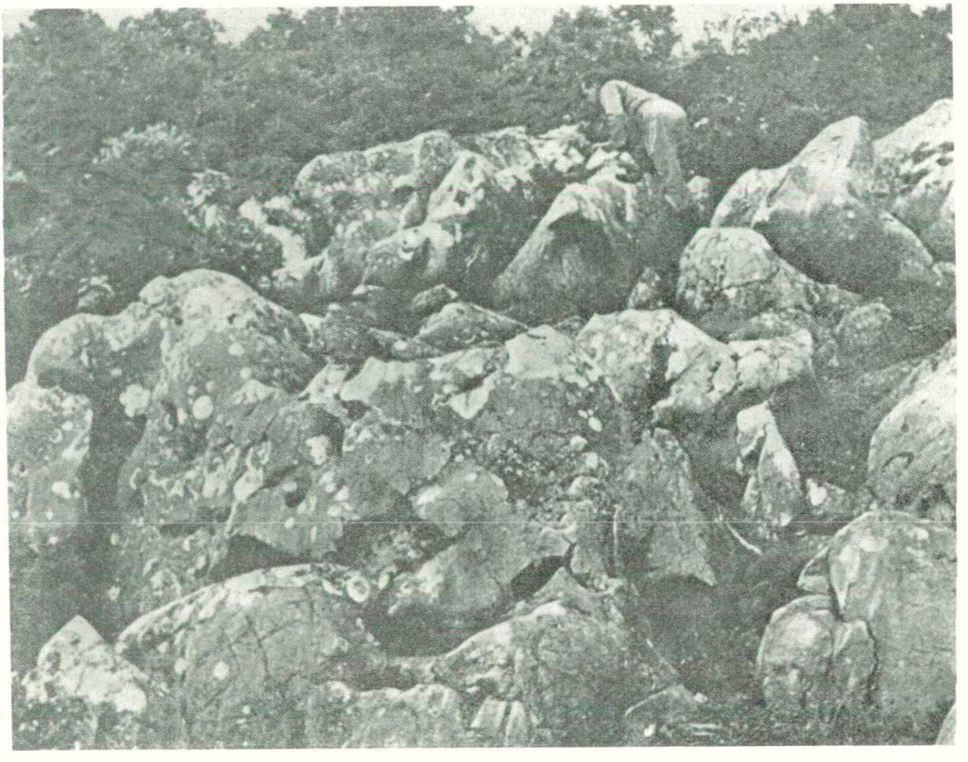

Figure 1. Rounded limestone lapies with root holes, the typical result of evolution under a soil cover, on a flank of Baradla-tető at Aggtelek (photo by HOLLENZER)

This effective "metamorphism" of lapies forms is so regular, even quantitywise, that, for instance in the various areas of the Dalmatian Karst, *the state of advancement of this reshaping* (via comparative morphoanalysis) permits a good approximate estimate of the *time elapsed* since the baring of the rock in any particular locality. Figures 3 and 4 give a concrete illustration of this.

The removal of the plant and soil cover also has other consequences, of course, resulting in a distortion of the karstifying process.

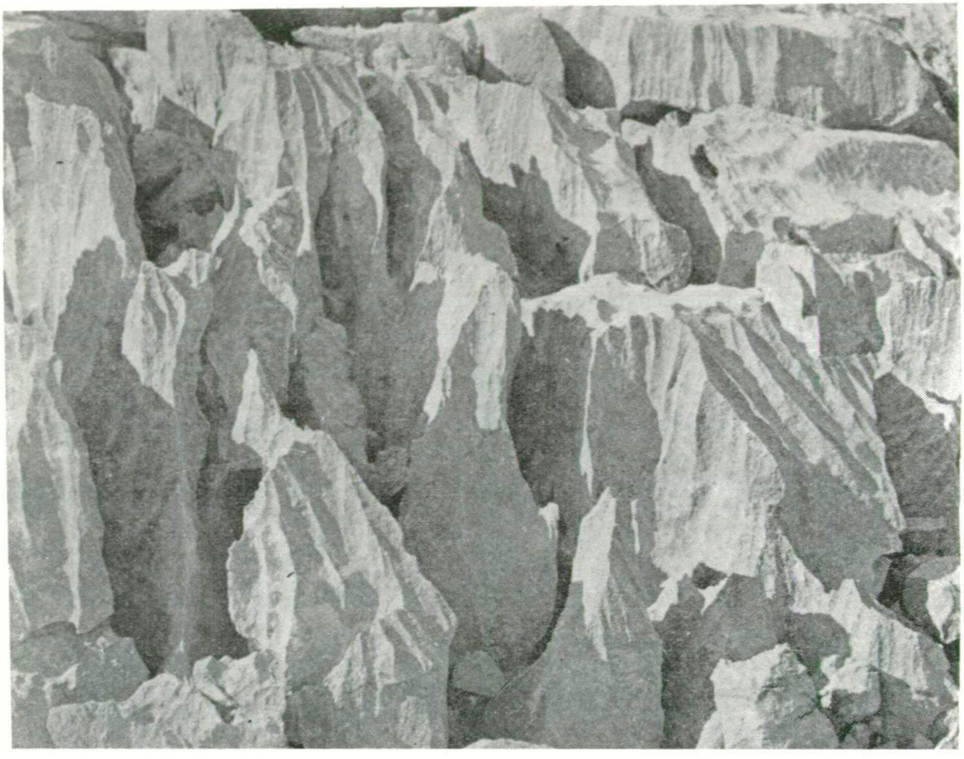

Figure 2. Secondary dissection of barren lapies of the Dalmatian Karst by parallel runoff furrows: the lack of a preferred orientation among the blocks of rock clearly indicates the subcutaneous sculpture of the basic forms

Prior to degradation, karst soils covered with forest, and even those supporting only a lawn association, supply an evened-out flow of ground water to the underlying limestone. This is a consequence of the natural water storage capacity of the soil, which enables it occasionally to take in and transitorily store quite substantial amounts of precipitation. In the process, a large proportion of the pores between the soil particles become filled with water; some soils swell considerably as a result.

On the other hand, rain immediately runs off barren karst surfaces, being partly absorbed into the fissure system of the karst rock, and so even a few hours after a summer shower the limestone surface is again completely dry. This is why *drippings of comparatively uniform discharge, active the year round, invariably occur in any dripstone cavern beneath wooded karst surfaces, whereas stalactites with markedly variable dripping rates occur almost without exception in cavern sections underlying barren karst surfaces.* These latter dripstones frequently include some for which there may be periodic cessation of the water discharge.

This is borne out convincingly by my recordings of the water discharge rates of some stalactites in the Baradla and Béke caverns at Aggtelek (Fig. 5).

My Slovenian observations in the nineteen-sixties convinced me that there are also other, sensitive relationships between the plant-cover pattern of the ground surface and the resulting state of the soil, and also the nature of the karst process. First and foremost, there are at times considerable differences in the dynamics of dripstone formation in cavern sections lying beneath covered and barren karst surfaces. *Dripstone formation rates greater by several orders of magnitude were found beneath forest-covered reliefs than beneath degraded planinas.* Especially in short-range comparisons, dynamisms differing by a factor of 10^3 were observed. This is understandable since some drippings of water dry up entirely from time to time under barren karsts.

Via the above factors, any significant deterioration in the original water-storage capacity of the soil and in the infiltration-evening role of the surface cover in eroded karsts will also lessen *the reliability of the yields of karst springs* surging in the karst area considered. In a karst in the process of degradation, spring discharges tend to become *irregular;* the advance of degradation entails increasing *extremes* in the yield and even in the water composition of the springs. Whereas the peak discharge prior to general soil degradation is likely to exceed the minimum by a factor of ten

Figure 3. A lapies field laid bare by total soil erosion subsequent to deforestation, near Hercegnovi, Yugoslavia. The lapies still reflect the influence of the subcutaneous process; the evolution of runoff furrows is quite embryonal. Deforestation took place about 80 to 100 years ago. (See also Fig. 4.)

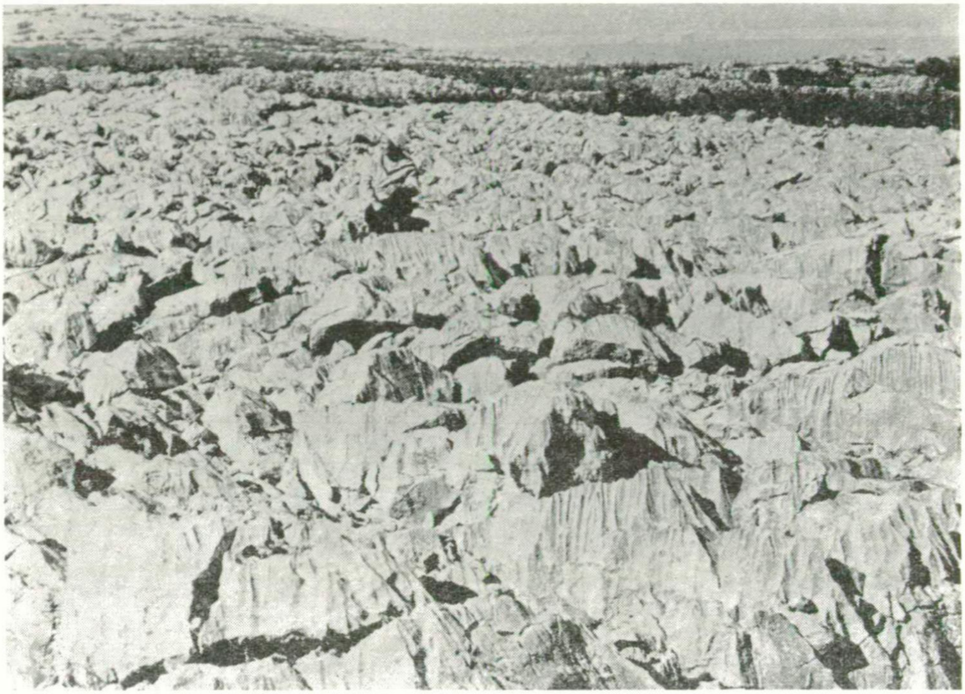

Figure 4. A lapies field laid bare by total soil erosion subsequent to deforestation, near Hercegnovi (about 2 km from the site shown in Fig 3). The lapies shows hardly any remains of the primary forms due to the subcutaneous process; the well-developed runoff furrows are indicative of an advenced stage of barren-karst corrosion. The time elapsed sinci deforestation is at least 400 to 600 years.

at most, after degradation the peak discharge may exceed the low-water discharge by as much as a factor of one hundred (KESSLER 1954, 1956). This also has a deleterious influence of course on the purity, the natural filtration, the possible bacterial contamination, etc. of the water, even in the case of A-type springs.

In a general way it seems that although the degradation of the karsted drainage area increases the total yield of the area on a year-round average, by increasing the proportion of durably infiltrated water, at the same time the accompanying extreme fluctuations of the discharge and the deterioration of the water quality are very unfavourable changes wherever it is intended to use the spring to *supply* some settlement, for example. Consequently, the afforestation of karst surfaces within the drainage areas of one or several karst springs ensuring the water supply of a town is a high-priority task for the society. Hungarian examples of such towns are Miskolc, Pécs and Borsodnádasd. Neglect of this task, or even allowing the processes of degradation to continue, will inevitably result in the deterioration of the reliability and quality parameters of the spring.

Anthropogenic influences deflect the evolution of the natural plant cover over a karst region almost invariably in the direction of degradation; there are also some other sensitive intensity indicators of the connected karst processes, however. One of these is *the changing colour of dripstones in caverns,* perhaps the most sensitive record of rates of degradation in the past as well as in the present.

Reference can be made in this context to my examinations concerning the colour, structure, chemical and mineralogical composition, locality of occurrence and abundance of dripstones in the caverns of the North Borsod Karst in Hungary (L. JAKUCS 1960, 1962), which clearly led to the following inferences:

1. The abundance of non-carbonatic contaminations is least in the dripstones of those cavern sections under a relief with an uninterrupted forest cover and a natural soil profile.

2. The dripstones under barren karsts are often inactive, dull of surface, and usually yellow, brown, ochre or a clayey-grey in colour.

3. Where the plant cover has died off recently, the surfaces of stalactites and stalagmites show a marked change in colour, usually towards a red tint. Areal erosion on the surface and the increased infiltration into the karst of the eroded clays and iron compounds results in a lower calcium carbonate content in recent dripstone formations; such layers tend to be friable and rich in non-carbonatic contaminating substances.

4. If the forest on the karst is renewed after a brief period of barrenness, the dripstones grow lighter once more, and the most recent layers are then clear again. In this way it is possible to infer the phases of surface degradation from the cross-sections of inhomogeneous dripstones in caverns; such phases may reflect either an anthropgenic influence, or a natural destruction of the forest, for example by fire. Not only do the interiors of such dripstones exhibit concentric shells of dripstone

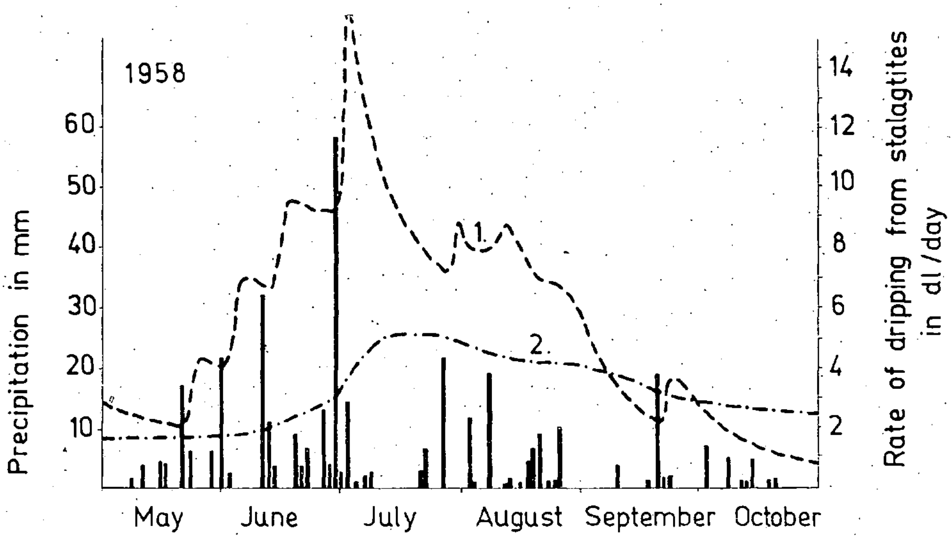

Figure 5. Typical differences in water yield of stalactites underlying a fully degraded, barren karst (graph 1) and a karst covered with a thickish humus soil under a forest (graph 2). The histograph shows the rainfall in the region under study during six months of 1958
1 = stalactite 3 in the „Hall of Columns" of the Baradla;
2 = stalactite 4 in the Béke Cavern

differing in colour and composition, but some of the calcium carbonate layers even wear a coating of clay. The calcium carbonate content of this intrastalactic clay may be as low as 1%. The clay coating is in turn surrounded by a calcium carbonate shell, this pattern possibly being repeated 5 or 6 times. This may occasionally reach such a degree that a broken-off stalactite can be drawn out telescope-fashion by deforming the plastic layers of clay contained in it (Fig. 6).

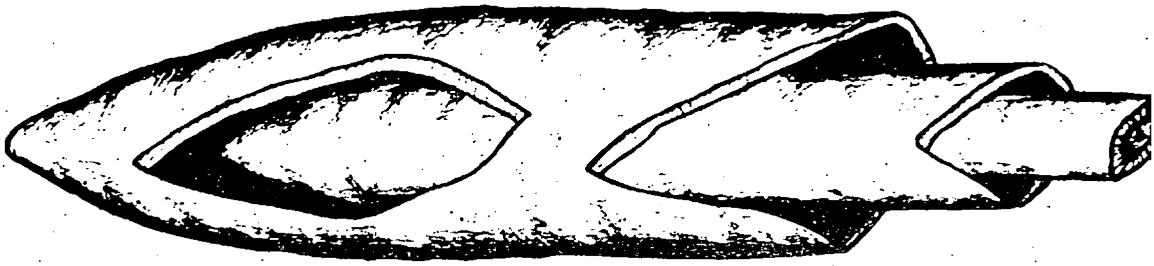

Figure 6. Structure of a telescoping stalactite indicative of ancient forest fires or other episodes of surface degradation. The soft clay intercalated between the calcite shells, deposited at times of degradation, can be washed out subsequently, in which case the broken-off stalactite readily slides apart (original)

In caverns underlying limestone planinas, where the terra rossa-type soil is rich in ferric oxide, the degradation of the soil and of the plant cover is clearly indicated by the redness of large masses of wall linings and dripstones, as in karst areas where the forest cover was destroyed the upsetting of the long-standing equilibrium of the soil cover permitted the waters to wash the degraded soil through the fissures of the limestone into the caverns. Comparison of cavern and surface maps reveals (L. JAKUCS 1960, 1962) that in the vicinity of the "Red Hall" or of the "Stone Toadstool Gate" in the Béke cavern of Aggtelek, for instance, where the red lining on the cavern formations is especially conspicuous and ubiquitous, a denudation caused by total deforestation has taken place over the last hundred years or so.

The washing of clay into the barren karst may occur locally at so high a rate that even over a few centuries it may result in a significant, and locally even complete *silting-up* of inactive cavern sections. Sedimentological and pollen-analytical methods applied to the muddy fillings in the "Fairytale Land" and the "Golden Street" of the Aggtelek cavern, and in the upper passage of the "Radish branch", as well as in numerous upper-level syphon bypasses in the Béke Cavern, etc. have demonstrated that silting-up over the last few centuries (during a period of general surface denudation in the neighbourhood) has deposited a bed of clay thicker than the aggregate deposits of the previous three or four millennia.

Such a fast process of silting-up and clogging of underground cavities therefore justifies the statement that *any anthropogenic interference with the natural plant cover of a karst region will initiate a period of intense changes and decay in earlier-formed karst features both on the surface and underground.*

Of course, the above considerations do not at all imply that it is altogether unfeasible to displace the process in the opposite sense, that is, to put a stop to degradation already under way, and even to reverse the trend. There are many examples to show how successful a timely and well-chosen method of reafforestation may be. According to P. JAKUCS, (1954, 1955, 1956), however, the task is far from simple. "Reafforestation must always start from the shrub-covered spots left over in the place of the former forest; it must employ everywhere the tree species of the ancient, natural plant cover that may be found still thriving on similar slopes of adjacent hillsides. The work of reafforestation must proceld gradually, with due respect to the natural succession of the plant associations. For instance, a lawn-covered spot should at first be planted with shrubs, and only after these have gained a foothold may one think of planting trees (in Hungary primarily hairy oak (Quercus pubescens)).

Any change in the natural plant and soil cover of a limestone planina will, as a matter of course, affect the intensity of every karst process connected with corrosion, including e. g. doline sculpture, or calcareous tufa deposition next to a spring. I have nevertheless picked out above only the formation of lapies and the phenomena of hydrology and sedimentation in caverns; the slowing of doline formation on the advance of degradation, as well as the reduction or cessation of calcareous tufa deposition from a karst spring whose waters are gradually softening, are processes whose *short-term morphological consequences* are not conspicuous, or not recordable at all with the tools available today, and this makes their discussion very largely theoretical.

REFERENCES

Jakucs L. (1960): Az aggteleki barlangok genetikája a komplex forrásvizsgálatok tükrében (Genesis of the Aggtelek Caverns in the light of complex spring tests) — Karszt- és Barlangkutatás, 1960. I.

Jakucs L. (1962): Über die Färbung der Tropfsteine in den Höhlen — Karszt- és Barlangkutatás, Bd. III. Jgh. 1961.

Jakucs P. (1954): Mikroklímamérések a Tornai-karszton, tekintettel a fatömegprodukcióra és a karsztfásításra (Microclimate recordings in the Torna Karst, NE Hungary, with a view to the mass production of timber and the afforestation of karst areas) — Annal. Hist. — Nat. Musei Nationalis Hungarici, Tom. V. 1954.

Jakucs P. (1956): Karrosodás és növényzet (Lapies formation and plant cover) — Földr. Közl. 1956. 3.

Kessler H. (1954): A beszivárgási százalék és a tartósan kitermelhető vízmennyiség megállapítása karsztvidéken (Establishing the infiltration ratio and the assured water yield in a karst region) — Vízügyi Közl. 1954. 2.

Kessler H. (1956): Karsztvidékek lefolyására és beszivárgására vonatkozó újabb vizsgálatok (Recent investigations into runoff and infiltration in karst regions. Report on the work of VITUKI for 1956.